DT # 46203
QA: NA
10/18/2005

International High-Level Radioactive Waste
Management Conference



Testing of Flow through Stress Corrosion Cracks

## Introduction:

One aspect of licensing the high-level nuclear waste repository to be located at Yucca Mountain, Nevada, is the determination of the inclusion of the effects of features, events, and processes (FEPs) on the performance of the repository. Among the FEPs evaluated are the advection of solids and liquids through stress corrosion cracks in waste packages and drip shields. The presence of one or more cracks or other small openings of sufficient size in a waste package or drip shield may provide a pathway for the advective flow of water (e.g., thin films or droplets) or solid material through a waste package or drip shield. The resulting flux may affect drip shield performance and/or subsequent dripping onto or into the waste packages. The objective of this set of tests involved the detection/non-detection of advective water flow through stress cracks similar to those that may occur in the drip shield or waste package. If sufficient flow volume was present then attempts were made to quantify the volume of water flow through a stress crack.

Literature was reviewed to identify previous studies and models that may be relevant to the current study of flow through stress corrosion cracks in a drip shield or waste package. Although no studies could be found that were directly applicable to our current problem, studies were identified that investigated portions of the overall problem. The papers that were reviewed were organized into the following categories: (1) maximum static head in a crack; (2) liquid impingement on surfaces [1]; (3) leakage through stress cracks [2]; and (4) dripping from cracks and fractures [3]. Because of the unique configuration and processes associated with the current problem of flow through stress corrosion cracks in drip shields and waste packages, experimental studies are needed to better understand whether flow can occur in stress cracks from impinging water droplets.

## Work Description:

Both static head and dynamic drop tests were performed on 316 stainless steel and titanium grade 7 blocks with prescribed aperture sizes, and a 316 stainless steel plate with laboratory generated stress corrosion cracks (SCCs). The testing block assembly consisted of two blocks with the precision ground surfaces bolted together in a special vice with shim stock separating the blocks to create the various aperture widths identified for testing (Figure 1). Block thicknesses of 5/8 and 1 in. were tested. Although a machined sample will not duplicate the crack surface morphology of actual SCCs, it does provide a conservative bounding representation relative to the apertures expected in SCC samples.

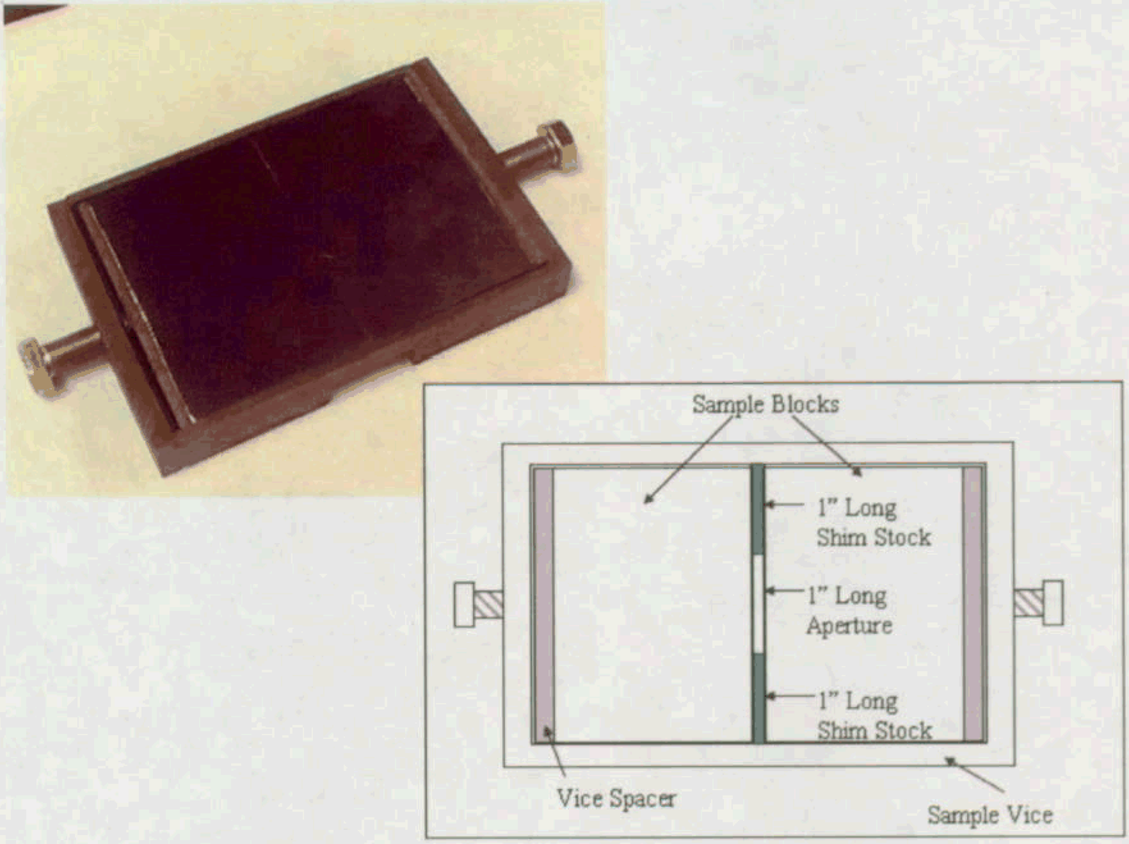


Figure 1. Stainless steel and titanium machined block sample vice.

The stainless steel plate was produced at the Lawrence Livermore National Laboratory (LLNL) as a part of a corrosion experiment. The SCCs were formed in the 1/2" thick 316 butt-welded 316 stainless steel plate by welding thick carbon steel beams to both halves of the plate perpendicular to the 316 stainless steel butt-weld and by exposing the surface to boiling magnesium chloride.

The purpose of the static head tests was to estimate the effective crack aperture by measuring the steady flow rate and pressure applied across the crack. The known apertures of the machined block samples were measured first to test the method, and then the effective apertures at two locations (location 1 and 2) on the SCC plate were measured (Figure 2). Aperture sizes in the blocks samples included 12.7, 25.4, 50.8, and 101.6 μm. The method used to measure the effective apertures assumed a steady, fully developed, laminar flow through the crack. The resulting analytical solution (Eqn. 1) was used to estimate the aperture from measurements of flow rate and applied pressure. In addition to the pressurized static tests, low pressure static head tests were conducted on the 5/8 in. thick stainless steel and titanium blocks with the purpose of determining the water column head that could be supported by apertures of 12.7 and 25.4 μm.

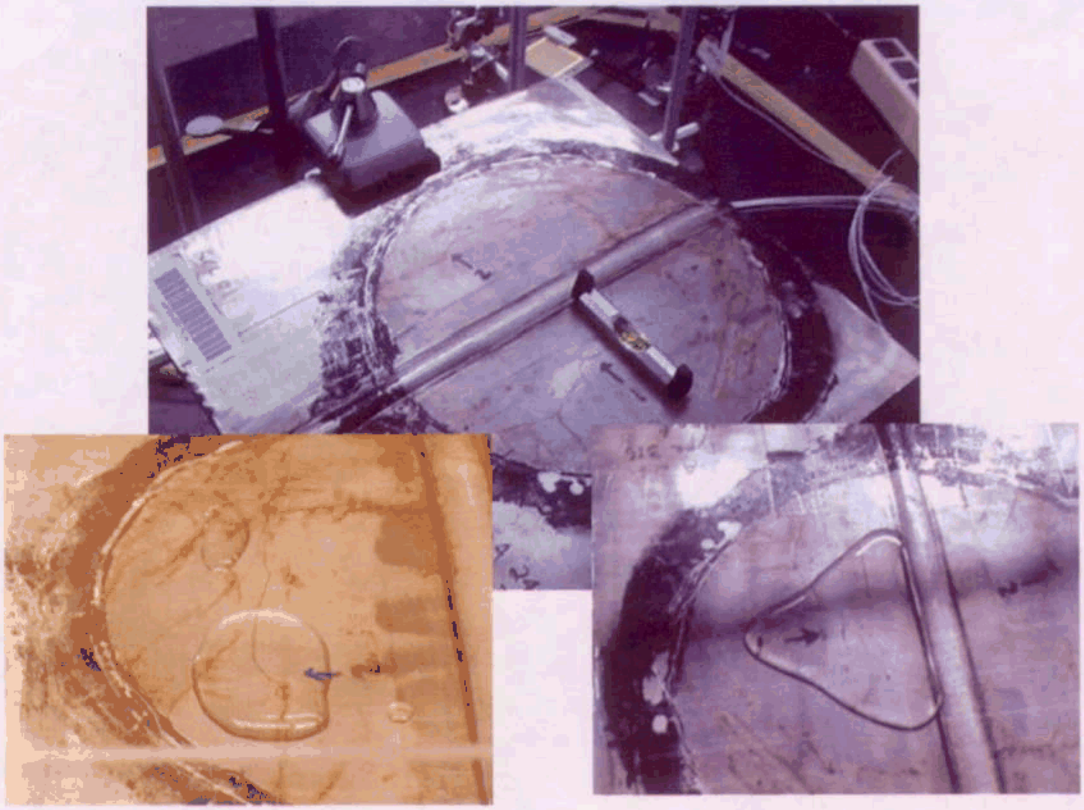

Figure 2. Stainless steel stress corrosion crack plate, locations 1 and 2.

$$b = \left( \frac{12\mu}{\rho L} \frac{\Delta m}{\Delta t} \frac{H}{\Delta P} \right)^{1/3} \quad \text{(Equation 1)}$$

Where,

- b = estimated crack aperture
- $\mu$ = dynamic viscosity
- $\Delta m/\Delta t$ = change in water mass over time
- H = plate thickness
- L = crack length
- $\Delta P$ = change in pressure across crack
- □= density of water

The dynamic drip tests were performed by dripping water onto the sample apertures in an attempt to force water through the crack with the impulsive force of the moving droplets. The dynamic tests were performed at two different drop heights that represent the falling distance from the drift crown to the drip shield (2.2 m) and from the drip shield underside to the waste package crown (0.4 m). Tests were performed with the sample surface oriented at three different angles representing the curved surface of a drip shield or waste package: 0° (horizontal), 30°, and 45°. The tests were conducted inside a test chamber where relative humidity was maintained at approximately 75-80%.

Results:
The resulting aperture calculations showed that apertures in the stainless steel blocks were measured with an average deviation from the actual of 22.79 +/- 25.83 %. The maximum deviation was 85.8 % and the minimum 0.30 %. Results from the low pressure static tests showed that the stainless steel blocks with an aperture of 12.7 μm supported a static water column of 5 mm without breakthrough for over 130 minutes, and an aperture of 25.4 μm supported a 10 mm static water column without breakthrough for over 160 minutes. A 12.7 μm aperture in the titanium blocks supported a static water column of 5 mm for over 130 minutes, and an aperture of 25.4 μm showed break through with a 5 mm water column in approximately 104 minutes. Apertures measured in the stainless steel plate at locations 1 and 2 resulted in effective aperture measurements of approximately 32 μm and 56 μm. Observations and measurements of the surface apertures at the two drip locations (1 and 2) revealed surface apertures of 381 $\mu$m and 127 $\mu$m.

Dynamic drop tests on the stainless steel and titanium blocks showed water breakthrough for all apertures at a drip height of 2.2 m for 0° and 5° impact angles, while no breakthrough was observed at 30° and 45°. The average breakthrough mass was 1.56 % (n=3) of input mass for the stainless steel blocks and 1.35 % (n=3) for the titanium blocks. Dynamic drop tests on the stainless steel plate showed breakthrough at all angles (0°, 30°, and 45°) and drip heights (0.4 and 2.2 m) at location 1 (32 μm), while no flow in any case was observed at location 2 (56 μm ). Average breakthrough mass for location 1 was 0.825 % of the total input mass.

Conclusions and Discussion:
Based on the results from both the SCC plate and smooth walled tests, we cannot rule out the possibility that water will penetrate SCC cracks in drip shields with apertures on the same order as those used in the tests, even with the uncertainty in the crack profiles (tortuosity). We can, however deal with some of the conservatisms inherent in the test set up. The major issue that will limit leakage through SCCs is the amount of projected drift seepage, which equates to an extremely low drip rate. The amount of water dripping onto a crack is in reality is much less than the amount used in the test (average test drip rate of 2 g/min). The total amount of water entering the drift is estimated in BSC 2004 [4] for present day, monsoonal, and glacial transition periods. The potential leakage through a SCC crack can be calculated by multiplying the percentage of breakthrough measured during the tests by the volume of seepage that may drip over a crack on a single waste package. Drift seepage estimates and the calculated potential for SCC breakthrough for the Topopah Spring lower lithophysal (Tptpll) unit (repository horizon) results in a maximum potential of $2.81 \times 10^{-6}$ kg/min for a 100 μm aperture. The total amount of water entering drip shields through SCCs must be bounded with other events upstream that must come into play before drops directly impact SCCs, i.e. the probability that a drip will occur over a crack, and the amount and nature of debris covering the cracks. Once the probability for these upstream events has been established, the test data in conjunction with the actual drift seepage rate and other limiting features can be considered to establish whether SCCs will leak in real-world conditions.

References:

[1] Harlow, F.H. and J.P. Shannon 1967. "The Splash of a Liquid Droplet." *Journal of Applied Physics , vol. 38,* p. 3855. Melville, NY: American Institute of Physics.

[2] Isozaki, T.; Shibata, K.; Shinokawa, H.; and Miyazono, S. 1990. "Measurement of Leak-Rate Through Fatigue-Cracks in Pipes under Four-Point Bending and BWR Conditions." *International Journal of Pressure Vessels and Piping, vol. 43,* pp 399-411. Barking, England: Elsevier Science.

[3] Su, G.W.; Geller, J.T.; Pruess, K.; and Wen, F. 1999. "Experimental Studies of Water Seepage and Intermittent Flow in Unsaturated, Rough-Walled Fractures." *Water Resources Research, 35,* (4), 1019-1037. Washington, D.C.: American Geophysical Union.

[4] BSC (Bechtel SAIC Company) 2004. *Abstraction of Drift Seepage.* MDL-NBS-HS-000019 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20041103.0003.